LIME IN AGRICULTURE

BY

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DOMINION CHEMIST

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FOREWORD

Though in recent years scientific investigations have added much to our knowledge of the functions of lime in the soil, the use of lime in agriculture is an exceedingly old practice. A study of the history of agriculture shows that the employment of lime for the amelioration of soils has been encouraged and again deprecated. This really means that there is a use and a misuse of lime. Unless rationally employed, the immediate advantages may be followed by decreased yields due to soil impoverishment. On the other hand, lime and carbonate of lime may be used with much benefit, increasing crop production without impairing the soil's fertility. It therefore behooves the farmer to understand the nature and agricultural functions of lime and its several compounds, to know what may be expected from them and, in a general way, their effect on soil fertility, chemically, physically and biologically.

Information on this subject would appear to be timely, as, due largely to articles that have appeared recently in the agricultural press and the advertisements of those who have lime and ground limestone to sell, a very keen interest in the use of these materials has been awakened. Numerous inquiries are constantly being received from Canadian farmers, and more especially from those in Ontario, Quebec and the Maritime Provinces, respecting the application of lime, the relative merits of lime and ground limestone and other related matters. The writer, therefore, purposes in this bulletin to present, in succinct and popular form, information on the more important phases of the question. No attempt will be made to write a scientific treatise on the subject and technicalities involving a knowledge of chemistry will, as far as is practicable, be avoided, but the farmer who would conduct his operations rationally and with an expectation of profit ought to realize that it is only by a clear understanding and mastery of principles that success can be attained.

THE NATURE OF LIME AND LIMESTONE

Our first inquiry, since its answer has a fundamental bearing on the whole subject, must be as to the nature and composition of the several lime compounds used in agriculture and the relationship that these bear to one another.

LIME

Lime is known under several names: quicklime, burnt lime, caustic lime, stone lime, etc. Chemically it is calcium oxide; that is, a compound of the two elements calcium and oxygen. Its characters, as it appears in commerce, in hard, whitish-grey lumps, are well known. It is somewhat caustic to handle and breaks down or " slakes " on the addition of water, with the evolution of much heat.

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It is usually prepared or manufactured by heating limestone (carbonate of lime) with wood or coal in a specially constructed kiln. Occasionally other forms of carbonate of lime are employed for this purpose, such as marl and oyster shells, both of which may yield very good lime. The intense heat of the kiln decomposes the carbonate, carbonic acid gas (carbon dioxide) being driven off and caustic or quicklime remaining.

The purity or quality of any sample of lime will naturally depend upon the quality or composition of the limestone used and the thoroughness with which it has been burnt. The freshness of the lime is also a matter of some importance, since exposure to air, and especially damp air, causes a gradual slaking and finally a conversion into carbonate.*

SLAKED LIME

Slaked lime, known in chemistry as calcium hydroxide, results from the union of water with quicklime. The process of slaking, or adding water to the lime, is commonly practised by builders in the making of mortars, and, as already remarked, is accompanied by the generation of a considerable amount of heat. The result is a whitish-grey or greyish-white (according to the quality of the lime) powder having properties that are distinctly caustic and alkaline.

Air-slaked lime results from the long exposure of quicklime to the air. The lime first absorbs moisture, being converted into the hydroxide (slaked lime) which then takes up and combines with carbonic acid (always present in the atmosphere) to form the carbonate. It will be obvious, therefore, that air-slaked lime is of a variable composition; it may be essentially slaked lime with a small percentage of carbonate, or it may be largely carbonate of lime with traces only of slaked lime, depending chiefly upon the length of time the lime has been exposed.

LIMESTONE

As pointed out, limestone is essentially carbonate of lime, or speaking chemically, a form of calcium carbonate. Limestones are not all identical as to composition; some contain notable amounts of carbonate of magnesium and are known as magnesian limestone or dolomite; others contain varying proportions of quartz, slate and similar inert rock material. Hence, ground limestone—the form used in agriculture—will be found more or less variable, the better qualities being almost pure carbonate of lime. A good quality of limestone will contain at least 80 per cent of carbonate of lime—or of mixed carbonates of lime and magnesia, as occurring in dolomitic limestones—while those of highest grade will contain 90 per cent and over.

Limestone of excellent quality occurs abundantly in many parts of Canada and outcrops, readily quarried and covering large areas, are to be found in almost all the provinces of the Dominion. For the following paragraph touching more particularly on this phase of the subject, we are indebted to the Director of the Geological Survey.

" Limestone is of rather wide distribution throughout the southern part of Canada, and particularly in the eastern half is within easy reach of the agricultural districts. In Nova Scotia there are several deposits on Cape Breton Island and on the mainland with a calcium carbonate content of 95 per cent or over. High-grade deposits are also found in the vicinity of St. John, New Brunswick. Deposits occur in southern Quebec and in the triangular area of Ontario lying between the St. Lawrence and Ottawa rivers. Much of Ontario southwest of a line running from Kingston to Georgian bay is underlain by

* Quick lime should be stored in a shed or bin that is well protected from rain or the entrance of water. The action of water in slaking lime results in the evolution of a very considerable amount of heat and the accidental access of water to lime in improperly protected places has not unfrequently been the cause of disastrous fires and the destruction of farm buildings.

limestone; some of this is magnesian, but high-grade deposits occur. Similar formations are exposed in Manitoba in the vicinity of lakes Winnipeg and Winnipegosis, but unfortunately there are no deposits west of this until the Rocky mountains are reached. Here limestone is found in abundance; it also occurs at various points in British Columbia."

COMPOSITION OF CANADIAN LIMESTONES

In the following table the locality and carbonate of lime content are given of a number of Canadian limestones analyzed in the Farm laboratories. These have not been specially selected nor do they comprise all the analyses made during the past few years, but they may be regarded as fairly indicative of the limestone available in the several provinces for agricultural purposes.

Lab'y No.	Locality	Carbonate of Lime Per cent
New Brunswick—		
20267	Petticodiac	94.10
20881	Torryburn	93.15
21145	Hillsboro Quarry	86.75
21146	Upper Dorchester	84.00
23052	Lake Edward, Victoria	26.31
25626	Hartland, Carleton	90.94
26449	Elm Tree, Gloucester	98.00
26453	Petit Rocher Station	88.75
26603	St. Charles Settlement	98.25
30837	Queenstown, Queens	94.00
38726	Lower Millstream	83.81
45253	Northumberland County	94.55
50296	Upper Kent	66.09
52210	Northwest Miramichi	71.25
Prince Edward Island—		
51055	Department of Agriculture	85.13
Ontario—		
20214	Merivale	88.25
20846	Kirkfield	77.98
22822	Chaffey's Locks	92.25
24146	St. Mary's Perth	90.99
24147	Point Anne, Hastings	93.75
24650	Point Anne, Victoria	90.23
26119	Haldimand County	95.81
27344	Collin's Bay	72.19
28409	Erinsville	96.50
28717	Seaforth	96.43
Nova Scotia—		
21180	Marble Mt., C.B.	72.75
23484	Cheticamp, Inverness	93.87
23485	Cape George, Antigonish	71.62
23486	Ste. Anne's, Victoria	92.92
25067	Central Cariboo	94.12
26646	Riverton	89.80
29707	Pictou County	75.00
41767	Joggins Mines	52.51
54094	Stellarton	94.00
British Columbia—		
23035	Surrey Centre	98.75
23744	Strandley	98.87
25592	Alberni	28.18
45146	Edgewood	78.70
46288	Kaslo	93.68
52018	?	95.00
Quebec—		
23547	Point Fortune	49.25
24282	Black Cape	85.15
25550	St. Louis de France	96.68
25607	Point Fortune	94.06
25788	Ste. Luce Station	72.10
26853	St. Louis de Champlain	93.44
30576	Escuminac	86.00
25710	St. Maurice	90.55
50673	Mount Joli	76.50

MARL

Marl or shell marl though of variable quality is essentially carbonate of lime. Many samples analyzed in the Experimental Farms laboratories have shown over 90 per cent of this constituent, while others, owing to the presence of notable amounts of sand, clay and organic matter, have been found to contain as low as 30 per cent of carbonate of lime. It is perhaps the most common of calcareous deposits, being found to a greater or less extent in nearly all the provinces in the Dominion. Its usual occurrence is a bed or deposit from a few inches to several feet in thickness, on old lake bottoms, frequently overlaid by deposits of muck, an organic material formed by the partial decay of aquatic and other vegetation and itself a very useful amendment for soils poor in nitrogen and humus. It may frequently be recognized by the presence of many small shells, which are embedded in a matrix of carbonate of lime formed from the disintegration of previous generations of shell-fish, with an admixture of clay, silt, etc. Marl may always be identified by giving a copious effervescence on the addition of a little strong vinegar or other acid. When freshly dug it is usually a greyish, pasty mass; on drying it becomes lighter in colour and forms

a mass which may be easily crumbled. After digging the only preparation necessary is air-drying and crushing, to permit of ready application and uniform distribution on the land. No special machinery is necessary for the crushing operation, a field roller or an improvised pounder or tamper would answer very well.

No reasonable amount can injure the soil, but we would suggest 2 to 5 tons of the air-dried marl for light and sandy loams and from 10 to 30 tons on heavy clays. Its application may be made by scattering on the ploughed land and harrowing in, either in spring or fall.

Canadian farmers have not as yet fully realized the agricultural value of marl. Not infrequently farmers may find it on their own property or easily accessible in their own neighbourhood, procurable at a minimum of expenditure, possibly merely at the cost of digging and hauling. Under such conditions there is no necessity to buy lime or ground limestone; there is within easy reach and cheaply obtainable a material which may vastly improve their soils and increase their yields.

LIME KILN REFUSE

This waste product from lime kilns is extremely variable in composition, but may be said to consist essentially of unburnt limestone, quick-lime and air-slaked lime. Occasionally fairly large percentages of sand and other inert materials are present, and these, naturally, reduce its value. Frequently it may be obtained in the neighbourhood of kilns at a very low figure, much below its real lime value, in which case it may prove an economic source of lime for agricultural purposes. This material, crushed or ground, has been put on the market and sold under the name of "Agricultural Lime." As no two samples are alike as to composition, purchases should only be made on guaranteed analysis as to the percentages of quicklime, carbonate of lime, etc., present.

Lime kiln ashes are a mixture, consisting chiefly of the ashes from the fuel used with variable amounts of quicklime, unburnt limestone, sand, etc. Wood is the common fuel employed in this country and hence these ashes contain more or less potash. Samples have been analysed in the Farm laboratories that contained as much as four per cent potash and, again, other samples have been shown to contain less than one per cent of this element.

GAS LIME

Gas lime is a waste or by-product in the purification of illuminating gas and may frequently be obtained from the city gas works for the cartage. It is quite variable in composition but may be considered for practical purposes as a mixture of slaked lime, carbonate of lime, several sulphides of lime and certain tarry matter. The sulphur compounds present in the fresh gas lime, though imparting an insecticidal value, are distinctly injurious to growing vegetation, and hence the immediate incorporation with the soil of this material as freshly drawn from the works is not to be advised, excepting in cases where it is used specially for the destruction of certain noxious insects. Exposure to the air, as in small heaps in the field, will, however, in the course of two or three months convert these harmful sulphur compounds into harmless sulphate of lime—a valuable form treated of in this bulletin under the heading of gypsum. The fully exposed material, now essentially carbonate and sulphate of lime, may be spread and harrowed or lightly ploughed under. Thus used it will be found a useful amendment for neutralizing soil acidity and indeed for all the purposes for which ground limestone and land plaster are employed. It has more particularly been used effectively on stiff clays and mucks; on these the application may be say five tons per acre, but on ordinary loams that are not exceedingly acid, the dressing may be in the neighbourhood of two tons per acre.

THE AGRICULTURAL FUNCTIONS OF LIME AND ITS COMPOUNDS

The chief and outstanding objects of applying lime or carbonate of lime are two: The correction or neutralization of acidity or sourness and the improvement of tilth or mechanical condition of soils. Incidentally, they serve other useful purposes, as will be pointed out in the course of this discussion.

ACIDITY OR SOURNESS

Acidity or sourness in a soil is a property or quality distinctly detrimental to the thrift of most farm crops; lime and carbonate of lime combine with and neutralize the soil's acids and the excess used renders the soil slightly alkaline, a condition favourable to crop growth. In this way lime and other alkaline lime compounds may restore and enhance fertility.

Wet, low-lying and ill-drained soils are especially apt to become sour. Soils consisting essentially of vegetable organic matter, as mucks and peat loams, are usually, though not invariably, sour. Again, strange as it may seem, many light, upland soils are slightly acid, presumably by reason of the washing out and leaching away of their original store of carbonate of lime or its withdrawal by many years of cropping.

In all soils, but more especially in sandy and gravelly loams, there is a tendency for the lime compounds to disappear, partly through removal by crops but more particularly by their solution and passage into strata below the zone occupied by the growing roots. Carbonate of lime is fairly soluble in water containing carbon dioxide—and soil mixture is usually saturated with that gas—and thus the soil's lime is constantly washed downwards and may largely be carried off by the drainage water. This fact explains the presence of carbonate of lime in the waters of our rivers, lakes and wells, and it is in this way that thousands of tons of this valuable constituent of our soils annually find their way to the sea. Once the available lime has disappeared, the tendency will be for the soil to become sour. Some soils, by reason of their origin, are well supplied with carbonate of lime for years of cultivation. Such are almost invariably strong, productive soils, and stock fed on their crops are thrifty with plenty of " bone." But there are other soils—especially many clays, silts and mucks—that are poor in lime from the outset and these, under cultivation become poorer and poorer in this constituent.

Methods of Testing for Acidity with Litmus Paper

The usual test for acidity or sourness in a soil is blue litmus paper; if this is turned red the soil, we may conclude, is sour, is practically destitute of carbonate of lime and will be benefited by liming or an application of marl or ground limestone.*

Blue and red litmus paper may be purchased at any drug store. It is very cheap and it is well to get the best quality obtainable. It can frequently be bought in small books containing twenty-five to fifty strips of the paper, each about one-half inch wide by two to three inches long, protected by a heavy paper or cardboard cover. These " books " are a very convenient and suitable form in which to have the test paper. They should be kept in a clean, dry, preferably wide-mouthed, well-corked bottle. When tearing or cutting out a strip of the litmus paper for use, it is desirable to use a pair of forceps (or some other simple instrument, as scissors), as the paper is sensitive and the fingers may cause its reddening.

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* Several chemical methods have been devised in recent years for determining a soil's "lime requirement," from the results of which may be calculated the approximate amount of lime required per acre. But these cannot be conducted outside of a laboratory.

The test may be made in several ways: we describe two, both of which are simple and, if carefully carried out, are reliable.

1. Take up, by means of a spade or trowel, a little of the surface soil from, say, half a dozen places on the area to be examined and mix well, using the trowel or a clean piece of board. Do not handle the soil. Take a small quantity (a few ounces) of the mixed soil and, putting it in a clean paper cup or tumbler, pour on a little boiled water and stir with a clean piece of stick or spoon until the mass is of the consistency of a very thick paste. Into this " mud " press a piece of blue litmus paper by means of a small stick or the back of the knife, inserting the paper until one-half to two-thirds of its length is within the pasty mass. At the end of fifteen minutes, carefully draw out the paper and note if the part that has been in contact with the soil has turned red. If so, the soil is acid. The rate and degree of reddening may to a certain extent indicate the degree of acidity present.

2. Place a strip of blue litmus paper in the bottom of a clean, dry glass tumbler (preferably flat-bottomed) and over it place a round " filter paper " (purchasable at a druggist's) or, if such is not readily obtainable, a piece of clean, white blotting paper cut to fit the bottom of the tumbler. On this put a few ounces of the soil to be tested, collected and mixed as already described, and pour on sufficient boiled water to moisten or wet the soil thoroughly throughout its mass, but no more, and set aside for half an hour or longer. To examine the litmus paper, the tumbler is inverted; viewed through the bottom of the glass its colour will be brought out well against the white filter paper. As a check and to ensure that any change in colour may not be due to acidity of the water or filter paper used, a blank test should be made in the same manner, but using no soil.

3. Recently, several equipments for determining the degree of acidity in the field have come into use. One of the simplest of these is " Soiltex," an outfit usable by farmers by which the degree of acidity is indicated, approximately, by the colour produced when the soil is moistened with a few drops of the indicator—a solution of brom-thymol blue—furnished in the outfit. The colour obtained is compared with the colour chart supplied from which is read the soil reaction and the amount of lime recommended.

INFLUENCE OF LIME ON TILTH

The influence of lime and its compounds upon the tilth or texture of the soil constitutes, as we have said, one of its most important and valuable properties. This is most marked and most beneficial in the case of clay loams, rendering them less sticky and cohesive when wet and more friable and mellow when dry. This is brought about by the aggregation or gathering together of the finer particles of the clay into larger units, a process known as flocculation. This flocculation vastly improves plastic soils, converting them from a stiff, impervious and almost untillable condition into one which renders them easier and less expensive to work. Further, this flocculation makes clays drier, warmer, better aerated, with a larger content of moisture available for plant growth and thus brings about a more favourable and ready condition for the extension of the root system in search of food. It permits the farmer to cultivate his clay soil earlier in the spring, for flocculation assists drainage, and thus will ensure, in most seasons, earlier seeding and increased yields. These effects of lime and its compounds on clays, which may be summed up in the word mellowing, may be considered on a par with their power to neutralize acidity.

On light soils—sandy and gravelly loams—lime and carbonate of lime are also beneficial, but not in so marked a manner as in the case of clays. The action here is to cement slightly the soil grains, rendering the soils somewhat heavier or closer in texture and thus, being less open and porous, they are less readily dried out in seasons of drought.

CHEMICAL EFFECTS OF LIME COMPOUNDS

Reference has already been made at some length to the neutralizing influence of lime and carbonate of lime upon the acids which may develop in a soil. There are other chemical reactions, however, though possibly of a subsidiary character and value, which take place on liming a soil, and these will now be briefly discussed.

First may be mentioned the action of lime compounds on the soil's store of inert unavailable potash. While the reactions which take place are not altogether understood, there is little doubt but that lime, as also the carbonate and sulphate of lime, has the tendency to decompose the insoluble potash compounds, the lime taking the place of the potash which is liberated in a form assimilable by plants. Thus the lime compounds may act as indirect potassic fertilizers. The effect is naturally most noticeable on clays and will be most apparent upon clover and other leguminous crops which more particularly respond to potassic fertilizers.

Secondly, lime and carbonate of lime react on the difficultly soluble and practically unavailable phosphates of iron and alumina of the soil, converting them into phosphates of lime, which much more readily yield their phosphoric acid for crop nutrition. It is this reaction that frequently makes the application of superphosphate (acid phosphate) so effective on soils rich in iron and alumina.

INFLUENCE OF LIME ON THE LIFE OF THE SOIL

It is well known that certain crops and certain trees thrive best on soils that are rich in carbonate of lime, but there is a microscopic vegetable life *within* the soil that also needs this constituent for its best development.

The larger number of the various types or classes of soils consist mainly of disintegrated and somewhat altered rock particles—grains of sand, particles of clay, silts, etc.—but an essential and important constituent of all arable soils is organic matter—humus or humus-forming material—the results of the partial decay of the roots, leaves, etc., of many generations of plants. This semi-decayed organic matter is the source and storehouse of nitrogen, the dominant and most costly element of plant food. But before this humus-nitrogen can be utilized by growing crops—and indeed by all the higher plants—it must be oxidized and converted into nitrates. This process, known as nitrification, is the lifework of certain vegetable micro-organisms or bacteria within the soil.

In soils destitute, or practically so, of carbonate of lime, and especially in ill-drained, water-logged soils, the decay of the organic matter is accompanied by the development of certain organic acids, generally classed or grouped as humic acid, and thus the soil becomes sour. This acid condition of the soil is distinctly unfavourable, practically inhibitive, to the life and development of the useful nitrifying organisms, for these can flourish only in a neutral, or rather slightly alkaline, soil. Lime and carbonate of lime neutralize these acids, making the soil suitable for the growth of these bacteria and, further, furnish a base or alkali to combine with the nitric acid produced by them. The nitrate of lime so formed is, no doubt, the principal, direct and immediate source of the nitrogen supply of our field crops.

Again, there is another class of bacteria the function of which is to fix atmospheric nitrogen within the soil, namely the *Azotabacter*, present, so far as we know, in fertile soils throughout the world. These have a valuable function to perform in adding to the soil's natural store of nitrogen, in building up a productive soil. And these also need for their development a slightly alkaline soil, such as is brought about by the presence of carbonate of lime.

And, lastly, there are the nitrogen-gathering bacteria associated with the legumes—clover, alfalfa, peas, beans, etc. These bacteria, residing in nodules or tubercles on the roots of the legumes, are able, in some way not as yet per-

fectly understood, to appropriate the nitrogen of the air existing in the interstices of the soil and to pass it on in a form serviceable to their host, where it is built up into the tissues of root, stem and leaf. The legumes generally are among our most important forage crops and they possess this unique property of leaving the soil richer in nitrogen from their growth. The bacteria that enable them to play this important role in agriculture cannot thrive in an acid soil, and thus it is that an application of lime or of carbonate of lime favouring their development encourages the luxurious growth of the legumes—the crops that enrich our soils in nitrogen and at the same time furnish us with forage high in the most valuable of all nutrients, protein.

COMPARATIVE VALUES OF LIME COMPOUNDS

From what has been said with respect to the composition of the various forms of lime used in agriculture, it will be clear that all are not of equal value, especially for the correction of acidity. It frequently happens, for instance, that lime, air-slaked lime and ground limestones may be all obtainable and the question then arises, which will be the best to purchase at the price offered?

In acid-correcting power and in furnishing available lime, and considering the various forms on a basis of equal purity, 56 pounds of quicklime is the equivalent of 74 pounds of freshly slaked lime and of 100 pounds of carbonate of lime whether it be as marl or ground limestone. Air-slaked lime, as has been pointed out, is partly hydroxide and partly carbonate, the proportions being dependent upon the length of time it has been exposed to the air; its value will, therefore, be intermediate between that of freshly slaked lime and the carbonate; that is, 56 pounds quicklime will be equal to a weight of air-slaked lime between 74 and 100 pounds. Presenting these facts in tabular form we have:—

2,000 lb. quicklime=3,571 lb. ground limestone and marl.
2,000 " " =2,643 lb. freshly slaked lime.

If quicklime were worth $5 per ton, ground limestone, equally free from impurities, would be worth $2.80 per ton and freshly slaked lime $3.80 per ton.

It may be repeated that these compounds as found in commerce are never absolutely pure; there may be considerable variation in composition among the several samples offered the purchaser. While, therefore, the above comparison, as to equivalent weights and values, may serve in a general way, an analysis is necessary when the exact lime value of any particular sample or samples is desired.

IS LIME OR CARBONATE OF LIME PREFERABLE?

The cost of material should not in all cases finally settle the question which of these two forms will be the better to apply. There are at least two other factors or conditions that should receive consideration—the character of the soil and the rapidity of action required.

Quicklime and slaked lime are not so desirable or safe for light, sandy and gravelly loams as are ground limestone and marl. These soils are usually poor in organic matter and the effect of lime, as is well known, is to hasten the oxidation and dissipation of this constituent. Hence, unless the lime were applied in small dressings (less than 1,000 pounds per acre) and at long intervals, the humus of the soil—certainly one of its most valuable constituents—might be unduly reduced in amount and thus the fertility of the soil seriously impaired. Carbonate of lime (limestone and marl) is much milder in its action and an excess can do little or no harm.

For heavy clays lime or slaked lime is to be preferred. It is true that these compounds are converted in the course of time into carbonate of lime within

the soil, but being more vigorous and active from the outset and being in a finer powder than ground limestone they pass more readily into solution, thus allowing a more complete and uniform distribution throughout the soil. As a result their influence in flocculating the clay particles will be more rapid and improvement in tilth will be more quickly obtained. For the same reason, the chemical action also of these forms is more vigorous than that of ground limestone and marl.

On soils rich in organic matter, mucks and peaty loams, the more caustic forms—quicklime and slaked lime—may be used, and in fairly large amounts —say two to four tons per acre—if strong acidity of soil is shown, as is frequently the case.

THE APPLICATION OF LIME COMPOUNDS

Quicklime.—Quicklime, as purchased, is in hard lumps of greater or less size and as such is, as a consequence, not suitable for a uniform distribution over the soil. It must be slaked. This is most readily accomplished by placing the lime in small heaps, say of a bushel each, uniformly disposed over the field to be treated. Pour a little water, about one-third the weight of the lime, so that the slaking may be gradual and a fine powder result, on each, cover the heap with an inch or two of moist soil and allow to remain for two or three weeks, when the lime will be thoroughly slaked and fall into a fine powder. To facilitate distribution and avoid a certain unpleasantness in handling it, it is well to mix the slaked lime with soil; the whole may then be fairly evenly spread by a shovel, and, if a damp day is chosen for the work, it may be accomplished without any great inconvenience.

Forty heaps of about 50 pounds or 25 heaps of 80 pounds each, is an application of approximately one ton per acre. On the heaviest soils the dressing may be two tons per acre, but on light and poor soils it should not exceed 1,000 pounds per acre,

There has been put on the market ground quicklime, but it is not generally obtainable. Its distribution from a wagon box is rather unpleasant work, and if this form of lime is used it is desirable to apply it with a special lime-spreader or distributor or with a special attachment made for the seed or fertilizer drill.

Slaked lime.—This is in the form of a powder and may be most conveniently, pleasantly and uniformly spread by employing a lime spreader or fertilizer drill, as mentioned in the preceding paragraph. It can, of course, be spread from a wagon box, but the operation is more or less disagreeable. If this method is adopted, the mixing of the slaked lime with a little fine soil is said to make the handling less unpleasant.

For these more caustic forms—quicklime and slaked lime—autumn is probably the best season for application, spreading on the ploughed land and immediately harrowing it in. The aim should be to incorporate the lime with the first three or four inches of soil. The tendency for all lime compounds is to sink, to be washed down by the rain, and, therefore, they should never be ploughed under.

Further, these more active forms of lime should never be supplied in excessive amounts or harm to the soil will ensue from a too rapid dissipation of its humus and nitrogen. This caution is especially applicable to light loams. It is better to make light applications frequently, say once in a rotation if necessary, than large applications at longer intervals. It is well to err on the side of too little than too much, and especially if the organic content of the soil cannot be constantly enriched.

Ground limestone.—The essential points to be remembered in the purchase of this form of lime are composition and degree of fineness. The matter of composition has already been referred to, but it may be added that an analysis should be demanded if the purchaser has no knowledge of the purity or quality of the limestone from which the material has been prepared.

If there is no guarantee as to fineness, an inspection or a trial with sieves must suffice. The more coarsely the limestone has been ground the slower will be its action in the soil—and the longer will it remain an active agent in ameliorating the soil. Generally speaking, the coarser-ground material is the cheaper, as grinding, and especially to a fine powder, is a rather costly operation. If a quick action is desired, a material 60 to 75 per cent of which passes a sieve 80 meshes to the linear inch will be found fairly satisfactory. If an immediate action is not of first importance a coarser ground limestone, say, 50 to 75 per cent, passing a 60-mesh sieve can be successfully used. In any case, all should pass a 10-mesh sieve.

The usual application is from one to three tons per acre, according to the character and the acidity of the soil and the degree of fineness of the material. Unlike quick and slaked lime, excess of ground limestone can do little or no harm, and the same holds true of marl.

The application of ground limestone and marl offers no special difficulty or unpleasantness; a spreader may be used or the material distributed by shovel from a wagon. They may be applied at any season of the year and are specially suited, as has been stated, for light loams and soils generally that are poor in organic matter. As with lime, they should be harrowed in, not ploughed under, or in the case of meadows or pastures, merely spread on the surface.

Special machinery is now manufactured to crush and pulverize limestone. Efficient mills have at least a capacity of two or three tons per hour. It is stated that employing such mills at the quarries ground limestone can be produced at a cost of 50 cents to $1.50 per ton. To this, of course, the cost of freight must be added when the purchaser lives at a distance from the source of supply, the rates for carload lots naturally being less than for shipments of a few tons.

The cost of the mill and of the necessary power—say 10 to 12-horsepower engine and boiler—to run it would probably be from $1,000 to $1,200 and this amount might be found too large for many an individual farmer, even though a valuable supply of limestone may be on his property. But in many districts, through agricultural organizations and other forms of co-operation, arrangements might be made whereby the limestone could be quarried, and the ground material supplied in a community at a minimum cost of production.

GYPSUM OR LAND PLASTER

Gypsum is a naturally-occurring sulphate of lime, and is found in vast beds or deposits in several provinces of the Dominion. Crushed or ground it forms the well-known land plaster. Gypsum contains about one-fifth of its weight of water known as the water of crystallization. When it is strongly heated (burned) this water is driven off and plaster of Paris results. This is not used in agriculture, but is much valued in the arts from its property of making a white hard cement when mixed with the requisite amount of water.

Gypsum may be valuable agriculturally in furnishing lime for plant growth, as it is fairly soluble in water, but since this lime is combined with sulphuric acid and is present in a neutral condition it follows the *gypsum has no value for the treatment of sour or acid soils.* For this purpose it cannot take the place of quicklime, slaked lime, marl or ground limestone, which, as we know, are essentially alkaline in character.

The two chief agricultural functions of land plaster are its property of flocculating clay and its effect or influence on the insoluble potash compounds setting free this element in forms available for plant use. The first of these functions makes it valuable for the dressing of heavy clay loams, which it improves in tilth by rendering them less plastic, more open and friable; in a word, mellower and more easily worked. The second role that we have spoken of constitutes it an indirect potash fertilizer, though, of course, it does not add to the sum total of the soil's potash. It is this property that makes land plaster specially beneficial as a top dressing for clover, a crop that particularly responds to potash manuring. The usual application is in the neighbourhood of 500 pounds per acre.

Land plaster possesses the property of "fixing" ammonia and for this reason is largely used in stables and cow barns. Thus employed, sprinkling or dusting the finely ground material in the stalls, it serves to retain the nitrogen of the very readily decomposable urine and incidentally to keep the atmosphere of the building free from ammonia, pure and sweet. It is this use of land plaster that we specially recommend, for by this means the value of the resulting manure is enhanced without any hindrance to the exercise of the other useful functions of this amendment subsequently in the soil.

An application of gypsum is valuable to lands affected by "black alkali." The sodium carbonate which such soils contain not only acts directly as a corrosive chemical, cutting into and eating away the plant tissues (especially at the immediate surface of the soil) but it acts most injuriously on the physical condition of the soil, puddling it and making it impervious and causing it on drying to form hard, refractory masses. The application of land plaster converts the carbonate of soda into sulphate of soda, a milder form of alkali as regards vegetable life and one less prejudicial to the physical condition of the soil.

Commercial land plaster is somewhat variable in composition; poor samples may not contain more than 60 per cent sulphate of lime, while high grades may reach 90 to 95 per cent. An analysis is necessary to determine the quality of any particular sample

THE USE AND MISUSE OF LIME

There is a use and misuse of lime; it can be employed legitimately to increase crop production and it can also be so used that soil impoverishment must inevitably follow. It has been shown that lime and its compounds may perform many important functions, in correcting acidity, in improving tilth, in promoting nitrification; nevertheless they are not fertilizers. It is true they may serve a useful purpose in some soils by furnishing available lime, but they do not add to the soil's store of nitrogen, phosphoric acid and potash, the essential elements that must be constantly returned if the soil's fertility is to be maintained or increased.

Lime and its compounds are to be regarded as amendments, materials that may improve the soil, chemically, physically and biologically, and thus make it more suitable for crop growth. They are not to be considered or used as substitutes for manure, for drainage or for tillage. The exclusive and excessive use of the more caustic forms (quicklime, slaked lime) must inevitably lead to exhaustion of fertility, for, as we have seen, they act as stimulants, setting free but not adding to the soil's stores of plant food.

The use of the milder forms—marl, ground limestone—is not fraught with the same danger to the soil's future, but even with these less active materials, it is incumbent that the soil's humus content be maintained.

When manure is regularly applied and a rotation adopted that periodically adds to the organic matter and fibre of the soil, judicious liming can do no harm; indeed, it may prove of the greatest benefit. The conditions that indicate the necessity or desirability of liming have been enumerated; in recognizing these conditions we must bear in mind that liming is but one feature in the economic and rational management of soils.

SOME RESULTS FROM EXPERIMENTS WITH GROUND LIMESTONE

Experiments conducted by the Division of Chemistry of the Experimental Farms in Eastern Canada during the past ten years have shown that at many points an application of ground limestone has been followed by increased yields, and particularly has been valuable for the clover crops, the establishment of which may be considered as the basis of profitable farming. The following instances illustrate the benefits that may be derived from ground limestone applied to soils deficient in lime.

In experiment III, at Kentville, N.S., on a sandy loam soil, a plot was treated to 600 pounds of a fertilizer furnishing 20 pounds of nitrogen, 40 pounds of phosphoric acid and 50 pounds of potash per acre in preparation for an oat crop in the year 1914 and yielded per acre 57·3 bushels of grain. Another plot, similarly fertilized, received ground limestone at the rate of 2,000 pounds per acre, and yielded 66·2 bushels of grain per acre—an increase of 8·9 bushels of grain due to the liming. In the second year (1915) of the rotation the fertilized but unlimed plot produced 2 tons 467½ pounds of clover and timothy hay per acre, while the fertilized and limed plot yielded 3 tons 760 pounds of hay per acre—an increase of 1 ton 292½ pounds due to the liming. In the fall of 1915 the strong growth of clover aftermath on the limed plot made it stand out in striking contrast to the others in the series.

In Experiment V, at Kentville, the influence of lime alone and in conjunction with fertilizers has been even more remarkably demonstrated.

Two corresponding series of plots variously fertilized were used in the liming experiment, one series being treated to an application of ground limestone, at the rate of 2 tons per acre, while the other series was unlimed.

Two three-crop (potatoes, grain, clover hay) rotations were completed in the year 1919, and the results from the six-year period (1914-19) follow. The ground limestone was applied in the fall preceding the commencement of each rotation and the fertilizers in the following spring.

AVERAGE YIELDS PER ACRE

	Potatoes 1914	Oats 1915		Hay 1919
		Grain	Straw	
First Rotation (1914-16)—	Bush.	Bush.	Lb.	Lb.
Neither lime nor fertilizer	55.9	30.9	1,615	720
Lime only	67.6	32.8	1,675	1,110
Fertilizers only	76.2	31.7	1,818	660
Fertilizer and lime	86.8	38.4	2,198	1,494
	Potatoes 1917	Wheat 1918		Hay 1919
		Grain	Straw	
Second Rotation (1917-19)—	Bush.	Bush.	Lb.	Lb.
Manure only	251.8	19.5	1,980	2,640
Manure and lime	313.4	29.8	2,260	4,090
Manure and fertilizers	292.4	23.7	1,996	3,126
Manure, fertilizers and lime	329.3	30.3	2,626	4,926

By comparing the crop yields in the rotations, 1914-16 and 1917-19, the favourable influence of the manure is strikingly apparent. But, though the

ratio of increase from the lime and fertilizers is somewhat less in the second rotation, the actual increase is greater than in the first rotation—unmistakable evidence of the more profitable use of fertilizers and of lime when applied in conjunction with manure.

A study of the figures representing the yields shows that lime stimulated the action of the fertilizers and their residues throughout the three-year period of each rotation.

The feature most prominent in the hay crops of both rotations was the remarkable influence of ground limestone—particularly noticeable on the basic slag plots—in promoting the growth of clover.

At Cap Rouge, P.Q., on a sandy soil, areas in barley, oats, wheat and peas were treated, in 1915, to an application of two tons of ground limestone per acre. The following results were obtained, the yields being expressed in pounds of grain harvested, per acre:—

Barley—Average of three varieties: limed, 3,900; unlimed, 945.

Oats—Average of five varieties: limed, 10,140; unlimed, 8,940.

Wheat—Average of four varieties: limed, 4,200; unlimed, 3,315.

Peas—Average of four varieties: limed. 7,080; unlimed, 3,495.

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